Title: Getting Back in the Black: An Interactive Decision-Support Tool to Aid Timely Management Decisions Associated with Alaska Black Cod (Sablefish) Discarding

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Abstract

Fisheries management decisions often depend on complex modeling, but conveying results in non-technical terms can be challenging for scientists lacking formal communication training. As co-management gains traction, it is imperative that scientists develop less esoteric methods to convey results in broadly accessible formats. Online tools are appealing because interactive applications align with many stakeholders' digital comfort zone and programming in R is a common skillset among fisheries scientists. We developed an online decision support tool to address a time-sensitive management issue (allowing discards of small, low-value fish) within the Alaska sablefish fixed-gear fishery. Based on catch projection models, discarding due to the proposed de facto minimum size limit (22 inches) were shown to have minimal impacts on the resource or revenue. Pairing a technical document with an interactive application helped convey results and may have improved understanding and transparency of a complex analysis. The sablefish example underscores the need for a paradigm shift from technocratic approaches to more interactive and accessible methods for conveying scientific results at the science-policy interface.

Keywords: fishery management, stock assessment, decision-support tool, harvest control rule, discarding

1. Introduction

The post-normal science paradigm, wherein scientists are embedded within the participatory policy formation process and not external to it, requires fisheries scientists to directly convey complex modeling results to managers and stakeholders (Goethel et al., 2019). Thus, scientists must develop novel methods to aid communication to diverse end users (Miller et al., 2019). Increasingly, interactive graphics are employed to allow users to explore and digest results more effectively, thereby, enhancing transparency and participation in the management process (Regular et al., 2020). Thus, it has been widely recommended that decision-support tools be complemented with interactive graphics to help participants understand tradeoffs in management options (Miller et al., 2019). By moving away from technocratic approaches that produce opaque technical documents, the review and decision-making process can be expedited through better insights gained via interactive tools.

However, identifying when the additional resources required to produce interactive tools are justified can be challenging. Currently, the North Pacific Fishery Management Council (NPFMC) is exploring options to remove full retention requirements in the Alaska fixed-gear sablefish (*Anoplopoma fimbria*) fishery, highlighting a situation where an interactive decision-support tool may be beneficial. Sablefish are a valuable resource ($124 million in ex-vessel value in 2022; NPFMC, 2024b) for which management decision-making by the NPFMC is complex. In Alaska Federal waters, sablefish are managed as a single population with quotas allocated among two fishing sectors: fixed gear (the primary directed fishery composed of longline hooks and pots) and trawl gear. Population dynamics for Sablefish are complex, given that they are long-lived (90+ years), have delayed maturity (fully mature at age-12), and demonstrate highly spasmodic and cyclic recruitment events (Goethel et al., 2023). A full retention requirement has been in place for Alaska's federal fixed-gear fishery since rationalization (i.e., implementation of management via individual fishing quotas, IFQs) occurred in the 1990s. The population has been rebounding rapidly from historically low biomass levels since 2016, primarily due to several recent extremely large recruitment events (Goethel et al., 2023). The associated influx of small fish to the fishery has resulted in market saturation, price declines, extreme size-based price gradients (Table S2), and generally dire socioeconomic conditions (NPFMC, 2024a,b). Stakeholders have requested a time-sensitive policy change to address declining socioeconomic conditions (NPFMC, 2021). Since 2019, the NPFMC has been considering a proposed action to allow discarding of small, low-value fish (< 22 inches total length) to improve economic conditions (NPFMC, 2024b). However, the proposed action has stalled for several years due to challenges with communicating scientific results, perceived lack of adequate impact analysis, and institutional inertia.

The research team hypothesized that an interactive tool to convey results could aid communication with the diverse array of potential users. Given that documentation of the use and reception of interactive tools for fisheries management decisions remains limited, the goal of this study was two-fold: 1) describe the development and role of a decision-support tool in the management process, highlighting one of the first instances that such a tool has been used by the NPFMC; and 2) update previous scientific analyses (e.g., Lowe et al., 1991) on the potential impacts of sablefish discarding. Results provide pertinent scientific findings that were used to inform time-sensitive management of Alaska sablefish. General recommendations are also provided for integrating interactive tools into management frameworks based on feedback and experiences with the sablefish online application. These recommendations may help guide future management endeavors for other species and regions or be applied in similar research contexts (e.g., management strategy evaluation, MSE), where collaboration between scientists, managers, and stakeholders is imperative.

2. Methods

The development of an interactive decision-support tool is described, which focuses on the key considerations that were undertaken to ensure the online application adequately addressed the needs of the time-sensitive management decision regarding sablefish discarding. Then, the catch projection model used as the basis of the discard analysis is summarized, emphasizing how the model calculates Acceptable Biological Catch (ABC) for Alaska sablefish, how it was adapted to incorporate discarding dynamics, and how a gross revenue module was integrated to highlight basic economic impacts. Finally, the array of discarding scenarios used to evaluate uncertainty in key assumptions (e.g., discard mortality rate, DMR) are described along with primary performance metrics.

Development of the Decision-Support Application

The online tool was built with the widely utilized 'Shiny' package (Chang et al., 2023), which enables production of interactive web applications and converts R code (R Core Team, 2022) to HTML. Shiny was chosen because of the development team's prior experience with the package, it is open source, and the Pacific States Marine Fisheries Commission offered to host a web-based application. The application's development focused on ease of access, usability, and effective communication for a diverse array of stakeholders. Given the short development timeline (< 3 months), functionality was emphasized over aesthetics. The application featured basic visualizations, refined with feedback from a select group of end users. After initial feedback, emphasis was placed on interactive features to facilitate hands-on exploration, primarily though zoom functionality and scenario selection (see Figure 1). Moreover, a landing page was integrated to provide background for each scenario, enabling the tool to function independently from the technical document. Scenarios were organized into tabs to avoid overcrowding, detail specific assumptions, and ease comparisons. Due to the number of scenarios (>100), model outputs were pre-processed before being input into the application. Development continued iteratively to enhance visualizations and overall appearance. The online application was posted publicly at https://shinyfin.psmfc.org/small_sablefish/ and presented at NPFMC meetings. Feedback on the application was gathered both formally and informally -- through written reports or direct correspondence with users -- but was not collected systematically. We qualitatively describe and summarize this feedback.

Projection Model

The full projection model dynamics and equations are described in Appendix A. Biological parameters (e.g., maturity, weight, and natural mortality; Table S1), fishery parameters (e.g., selectivity; Figure S1), and population parameters (i.e., recruitment and 2024 initial abundance-at-age) were taken directly from the sablefish stock assessment (Goethel et al., 2023). The model was built in Automatic Differentiation Model Builder (ADMB; Fournier et al., 2012) and is available at https://github.com/BenWilliams-NOAA/small_sablefish/tree/main.

The model included ages (30+), sexes (male and female), and fleets (fixed gear and trawl) with abundance-at-age calculated forward in time for 50 years (2024 – 2073; see Table A1 model equations). Spawning stock biomass (SSB) was based on the weight of mature females. Future recruitment was simulated by sampling, with replacement, from the assessment recruitment time series (1979—2021). This approach aimed to reflect the extremely spasmodic nature of sablefish year-class variability and the absence of a known stock-recruit relationship. Each scenario included 500 iterations to encapsulate variability, and the same random number seeds were used across scenarios to ensure consistency.

To better reflect recent dynamics, the current proportion of the quota harvested (i.e., 66%) and fishing mortality ratio among fleets (i.e., 74.5% from the fixed gear fleet) were assumed (sensitivity to both of these assumptions are presented in the online application). Discards were categorized as live or dead based on the DMR. In the projection model, discarding only occurred in the fixed-gear fleet as 100% mortality was assumed for trawl fleet catches. The proposed release action allows for optional retention of fish less than 22 inches total length, corresponding to the average length at age-3 for both males and females (Table S1). Therefore, a knife-edge (i.e., infinite slope) retention selectivity was implemented at age-3.

The NPFMC employs a sloped $F_{40\%}$ harvest control rule (HCR) for sablefish. Equilibrium spawner-per-recruit (SPR) analysis was used to determine the fishing mortality ($F_{40\%}$) that reduced SPR to 40% of the unfished level. The corresponding biomass-based reference point ($SSB_{SPR40\%}$) was calculated by multiplying $SPR_{40\%}$ with the average recruitment from 1979 – 2021 (25.3 million fish). When SSB exceeded $SSB_{SPR40\%}$, the ABC was based on fishing at $F_{40\%}$. When SSB was less than or equal to $SSB_{SPR40\%}$, the fishing mortality reference point was linearly decreased based on the ratio of SSB to $SSB_{SPR40\%}$. For the analysis, the HCR was adapted to include discarding, assuming that discards were directly linked to fishing effort (Goethel et al., 2018) and utilizing a total removals-based quota accounting system (Bohaboy et al., 2022). Although high-grading might occur under the proposed discarding action (leading to removals greater than the quota), the IFQ nature of the fixed gear fishery likely minimizes such practices, and the potential for high-grading was not addressed in the analysis.

Scenarios and Performance Metrics

The assumptions for each projection scenario are provided in Table 1. The full retention (*full_ret*) scenario emulates the current management regime, which prohibits discarding in the fixed-gear fleet. The remaining scenarios assumed all fish younger than age-3 were discarded and implemented constant prices (Table S2), unless otherwise noted. Scenarios tested sensitivity to DMR (*age-3_DMR_20%* and *age-3_DMR_35%*), discard age (*age-5_DMR_20%*), pricing dynamics (*var-$_age-3_DMR_20%*), and quota setting (*cap_var-$_age-3_DMR_20%*). For the alternate pricing dynamic scenarios, price was inversely proportional to landings, under the assumption that prices would revert to recent high levels as sablefish landings, and associated market saturation, declined. Minimum prices were associated with landings > 27 kt (i.e., 2023 landings and prices), while maximum prices were associated with landings < 12 kt (i.e., 2017 landings and prices). Price grades (Table S2) were scaled linearly for landings > 12 kt and < 27 kt. The alternate quota setting approach implemented a total landings cap of 15 kt, chosen as a tradeoff between maximizing price and catch volume, which represents an 'inventory management' strategy proposed to buffer fishery and resource collapses for spasmodically recruiting species (Licandeo et al., 2019).

The metrics used to compare scenarios included: SSB, total landings, dead discards, and gross revenue. The time series of these metrics provide indications of resource status and biomass of mature fish (i.e., SSB), fishery variability (i.e., landings), fishery waste (i.e., dead discards), and fishery performance (i.e., gross revenue). Gross revenue was tallied only for the fixed-gear fleet as reliable price grade information is only available for this fleet, and calculated as the product of catch-at-age (in weight) by sex and price per kilogram by age and sex as transformed from the price grade information (Tables S1—S2). Additionally, the proportion of years that SSB fell below the biomass reference level of $SSB_{SPR40\%}$ was presented. Comparisons were made through visual analysis of these metrics using simulation intervals (e.g., 50% and 85%) to illustrate variability.

3. Results

Interactive Application Feedback

User feedback indicated that the interactive application was well received as a complement to the technical document. With limited variation in performance metrics (Figure 2), conveying subtle changes through the static document proved challenging. For instance, the lack of strong impacts, both biologically and economically, was counterintuitive to many stakeholders' expectations. Therefore, the ability to sequentially add model runs via the checkbox feature and explore details with the zoom function were highlighted as effective for understanding differences (Figures 1 – 2). Thus, the co-development of an online tool enabled a deeper understanding through hands-on exploration. Despite initial skepticism regarding the decision-support tool (NPFMC, 2024a), the NPFMC Scientific and Statistical Committee (SSC, the regional scientific review body for federally managed marine species in Alaska) concluded that "evaluation of the large set of results was enhanced by the interactive Shiny tool [and]...[the SSC] encourages the further use of interactive tools for this and similar analyses" (NPFMC, 2024c). Other users also found the interactive tool valuable for independently exploring the underlying scientific assumptions and linking analytical decision points with policy options. Comments from users, including fishing industry representatives and NPFMC staff, indicated that the tool helped communicate results.

Discard Analysis

Discarding had minimal effect on performance metrics, with dead discards representing a small proportion of total landings (less than 1% for the *age-3_DMR_35%* scenario) and resulting in minimal increases in gross revenue (Figure 2). There was a less than 7% probability (i.e., risk) of annual SSB (across iterations) declining below $SSB_{SPR40\%}$ (120 kt), and the risk was similar for the full retention and age-3 discarding scenarios. The population trajectories were driven by the slow growth and maturity of sablefish, leading to lags in SSB and gross revenue as the large recent year classes gradually entered fully mature ages and higher value price grades. An older retention age (*age-5_DMR_20%*) led to increased discarding and gross revenue, with a negligible increase in the risk of being below $SSB_{SPR40\%}$. Implementing dynamic prices (*var-$_age-3_DMR_20%*) increased gross revenue, inversely proportional to decreases in landings. Despite yield remaining low with the landings cap HCR (*cap_var-$_age-3_DMR_20%*), gross revenue was consistently higher than for the catch maximizing $F_{40\%}$ HCR (Figure 2).

4. Discussion

Decision support tools are becoming ubiquitous in fisheries management to convey complex scientific analyses and help demonstrate tradeoffs in management options (Lynch et al., 2015; Bohaboy et al., 2022). Many online decision support tools are generalized and range in complexity and ease of use, but tend to have similar overarching goals of aiding managers in making structured decisions regarding the most robust management options available (see Appendix A in Regular et al., 2020, for a brief review of fisheries related decision-support tools). For instance, the FishPath tool (https://fishpath.org/the-tool; Dowling et al., 2023) requires minimal quantitative background by using an online questionnaire to highlight potentially robust data-limited management options. Conversely, the Method Evaluation and Risk Assessment (MERA, https://mera.merafish.org/app/mera; Carruthers et al., 2023) tool necessitates a background in fisheries modeling, but provides a graphical interface to more readily implement MSE and test robustness of candidate management options.

Although generic tools are extremely useful for identifying and narrowing management choices, more tailored tools can better inform decisions within the context of existing management frameworks or to address the complexities of a given system. For example, the tailored red snapper (*Lutjanus campechanus*) online MSE tool (http://gomredsnappermsetool.fiu.edu/) enables running MSEs for a specific resource (Gulf of Mexico red snapper) that better emulates the intricate dynamics of the study species, which would not be feasible with a generalized model (Zhang et al., 2024). Furthermore, numerous examples exist of tailored and interactive fisheries decision-support tools that have been directly utilized in a management context, yet they are often mentioned in grey literature (i.e., management technical documents) or available as links deep within regional fisheries management organization (RFMO) web portals. Two valuable examples of using interactive applications to convey complex stock assessment results to stakeholders and managers include the ‘NCAM Explorer’ for northern cod in Canada (https://paulregular.github.io/interactive-stock-assessment/NCAM_dashboard.html; Regular et al., 2020) and the International Council for the Exploration of the Seas' (ICES) 'VISA Tool' (https://github.com/ices-tools-dev/VISA_tool, with an example application for herring: https://ices-tools-dev.github.io/VISA_tool/her.27.25-2932.html; ICES, 2018).

When developing the online sablefish application our team borrowed many of the key features from previous tools, following the principles of open science as advocated by Regular et al. (2020), to reduce learning curves, increase efficiency, and provide the most robust tool possible in the short development time available. In common with both NCAM Explorer and VISA Tool, we utilized an R dashboard approach with tabs to delineate model runs along with interactive figures that integrated hover and zoom capabilities. However, because our analysis was less complex than a full assessment, we were able to simplify our outputs, reduce text, and generally appeal to a less technical audience. Thus, we attempted to implement a communication style that would appeal to or be more intuitive for stakeholders and managers with varying backgrounds and learning styles, with the goal of empowering the management decision-making process.

Given the relatively unique niche that the interactive sablefish tool filled (i.e., informing a time-sensitive fisheries management decision), feedback and experiences during its development, use, and reception provides an opportunity to develop recommendations for future operational decision-support tool endeavors (Table 2). As noted, our development process borrowed from existing tools in terms of interactive features and visualization approaches. Moreover, we followed many of the recommendations for tool development provided by Regular et al. (2020), and heeded the scientific communication advice suggested by Miller et al. (2019). Therefore, our main recommendation is to embrace open science and borrow useful communication approaches, visualization techniques, or any other features from existing interactive tools, as warranted. Moreover, researchers should carefully consider the purpose of the tool and how different end users (e.g., scientists, reviewers, managers, and stakeholders) might interact with it, then carefully consider key developmental features to tailor the tool to the specific needs of the application. Scientists should remember that the tool and associated graphics do not need to be perfect. However, early communication and feedback from select users during development can help to iteratively refine outputs that appeal to the target audience. Emphasis should be placed on including interactive features that help users more thoroughly investigate and explore the results.

Thus, it is important to carefully choose the coding package that can achieve the desired goals of the tool, while also being easily implemented by the developer team. A diverse team, particularly managers and facilitators, will help ensure the tool is approachable to all users by limiting jargon, identifying primary issues of concern, and to avoid overwhelming users with too many scenarios or technical details. Despite the benefit of interactive applications, their use should be carefully considered based on management need, and implemented synergistically with technical documents to better communicate take-home points.

Based on the results of the sablefish catch projections -- aided by the decision support tool -- and a broader impact analysis carried out by NPFMC staff (NPFMC, 2024b), the proposed sablefish discarding action has now passed scientific review by the NPFMC SSC (NPFMC, 2024c). The proposed action is currently being considered for final action by the NPFMC. Our analysis indicated that the proposed sablefish discard action would not have any strong consequences for the stock or fishery (NPFMC, 2024b). Results also supported previous analyses of sablefish discarding (e.g., Funk and Bracken, 1984; Terry, 1987; Lowe et al., 1991), which is noteworthy given the recent, rapid changes in fleet dynamics (i.e., the transition to longline pot gear; Cheng et al., 2024) and the more complex catch projection method implemented. The crux of these results is succinctly portrayed by Funk and Bracken (1984): "by the time sablefish recruit to the fishery, their period of rapid growth is over…[and] delaying harvest only reduces yield and landed value". Although analyses have been consistent, the underlying economic modeling remains limited and not well captured, given the complexities of sablefish markets (Sonu, 2014). Despite the limited impacts demonstrated by the results of the projection analysis, the discarding example provides a useful demonstration of how interactive decision-support tools can be utilized. Moreover, it highlighted the nuances involved with understanding discard provisions, which were often non-intuitive (e.g., tradeoffs in mortality processes at younger ages) for an array of management participants (including scientists), and are important to recognize when implementing time-sensitive management (Goethel et al., 2018).

Fishery management frameworks are becoming increasingly complex, which requires more technical analysis and necessitates broader stakeholder engagement with improved transparency (Goethel et al., 2019; Regular et al., 2020). Scientists working at the science-policy interface recognize the need to move beyond a purely technocratic approach to conveying results (Olson and Pinto da Silva, 2020). Interactive, online decision-support tools offer a solution, potentially enhancing capacity by reducing analysts' roles as 'gatekeepers' of information and fostering improved communication with stakeholders. By introducing stakeholders to the concepts of weighing trade-offs in performance metrics, decision-support tools can also improve involvement in other participatory processes, such as MSE, by helping to remove barriers to participation and reducing training time. For instance, the capped HCR scenario, although tangential to the discard analysis, elicited broad discussion on how catch stability constraints might be utilized within the context of an ongoing sablefish MSE project (https://ovec8hkin.github.io/SablefishMSE/index.html). Therefore, the broader use of interactive online applications to support decision-making, participation, and transparency in fisheries and natural resource management merits wider consideration, and represents an integral aspect of the burgeoning open science paradigm.

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6. Author Contributions

Conceptualization: DG

Data curation: DG, BW, SC

Formal Analysis: DG

Methodology: DG, BW

Project administration: CL

Software: DG, BW

Validation: DG, BW, SC
Visualization: BW
Writing – original draft: DG
Writing – review & editing: DG, BW, CL, SC

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8. Data Availability

Data generated or analyzed during this study are available in the GitHub repository, https://github.com/BenWilliams-NOAA/small_sablefish. The online application is available at https://shinyfin.psmfc.org/small_sablefish/.

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10. Tables

Table 1. Summary of the catch projection scenarios.

Abbreviation	Retention	Discard Mortality Rate (DMR)	Harvest Control Rule (HCR)	Price	% ABC Harvested	% Catch from Fixed Gear
full_Ret	Full	None	Sloped $F_{40\%}$	Fixed at 2023 Prices	66%	74.5%
age-3_DMR_20%	Age-3+	20%	Sloped $F_{40\%}$	Fixed at 2023 Prices	66%	74.5%
age-3_DMR_35%	Age-3+	35%	Sloped $F_{40\%}$	Fixed at 2023 Prices	66%	74.5%
age-5_DMR_20%	Age-5+	20%	Sloped $F_{40\%}$	Fixed at 2023 Prices	66%	74.5%
var-$_age-3_DMR_20%	Age-3+	20%	Sloped $F_{40\%}$	Dynamic (Inversely Proportional to Landings)	66%	74.5%
cap_var-$_age-3_DMR_20%	Age-3+	20%	Sloped $F_{40\%}$ with 15 kt Landings Cap	Dynamic (Inversely Proportional to Landings)	66%	74.5%

Table 2. Recommendations for development of interactive decision-support tools to inform fishery management decision-making based on lessons-learned from the sablefish experience.

Category	Lesson Learned	Recommendation	Sablefish Approach
Tool Development	Do not underestimate development time.	Set realistic expectations and use a reproducible, team approach.	One PI focused on analyses and one on tool development allowing simultaneous progress to meet strict deadlines and maximize skillsets. The use of GitHub aided code sharing and reproducibility.
	Focus on functionality over aesthetics.	Basic figures and features are ok if they clearly communicate the results.	Given tight management timelines, perfecting application appearance was deemed secondary. Managers and stakeholders were more worried about content rather than appearance.
	Early feedback from end users is critical.	Beta test and iterate to ensure format resonates with target audience.	Select stakeholders were sent early versions of the tool and feedback was used to iteratively improve presentation and critical features (e.g., addition of a landing page, scenario tabs, and zoom functionality).
	Choose a code package that achieves goals with minimal training.	The best package is the one that you can implement quickly and easily.	The 'Shiny' package was chosen for the sablefish application, because it contained the fundamental functionality that was needed (e.g., web-based deployment, interactive components), it was free and open source, and necessitated limited training given the team's experience.
	Emphasize interactive features.	Enable hands-on exploration for deeper understanding.	Stakeholders noted that the ability to compare desired scenarios and the zoom functionality were helpful features of the tool and improved understanding compared to the static technical document.
Science	Application development should not impede the analysis.	The scientific analysis should always be the first goal, and only pursue a tool if resources permit.	Given resources and expertise of the project team, it was determined that one PI could finish the analysis while the other developed the tool. Dividing tasks and reviewing each other's work led to synergistic developments and aided (rather than prevented) further analyses to be undertaken.
	Not all decisions require a tool.	Only pursue tool development if there is a well-established need.	The sablefish team carefully weighed the pros and cons of developing a decision-support tool and determined that it would save time by aiding communication and limiting future analytical requests.
	Convey uncertainty in multiple ways.	Include simulation intervals and sensitivity runs to illustrate potential uncertainty.	Because the sablefish tool was developed for diverse end users (e.g., scientific review bodies as well as stakeholders), multiple approaches to conveying uncertainty (e.g., through simulation intervals that appeal to scientists and sensitivity runs that address stakeholder concerns) was deemed important.
Communication	Outreach is critical.	Stakeholders need to be made aware of the tool and how to use it.	The sablefish tool was released in conjunction with the technical document just prior to the NPFMC review meeting. Many stakeholders were surprised and confused by the tool. Thus, outreach should have occurred well in advance of management meetings to make end users aware of the tool's availability.
	Clearly state the assumptions.	The application should be a standalone tool, which thoroughly describes the underlying analysis.	Given that we expected some stakeholders might use the tool without reading the associated technical document, we developed a landing page that served as a user guide and short description of the analysis. Tabs were used to separate scenario groupings and assumptions associated with those models were stated clearly.
	The tool must be approachable to stakeholders.	Limit jargon and integrate a diverse team to aid presentation of the tool.	We attempted to keep the language as plain as possible, but stakeholders were still confused by the scientific terminology and assumptions. By having a NPFMC staff member on the research team, it helped aid communication, while also informing how to structure the application to maximize understanding.
Decision-Support	Too many or tangential scenarios can add confusion.	Limit scenarios to those that directly aid decision-making.	Over 100 projection scenarios were developed for sablefish, which greatly exceeded those requested by the review body and NPFMC. Although some of the additional runs helped highlight (and reduce) uncertainty, others were tangential or interesting more as scientific inquiries and likely increased confusion.

Optimal result presentation format differs by end user.	Ensure that the tool and technical document work synergistically.	Both a technical document and an online tool were developed for sablefish as it was expected that different end users would want varying levels of technical detail (and a technical document was required for legal reasons). Many stakeholders noted that the two mediums worked synergistically to convey concepts.
Institutional inertia can derail tool development.	If a decision-support tool will aid communication, do not let initial resistance impede development.	Initially the sablefish tool was met with general apprehension due to concerns it would create more confusion. In the end, the application was well received and generally acknowledged as aiding understanding of the analysis.

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11. Figures

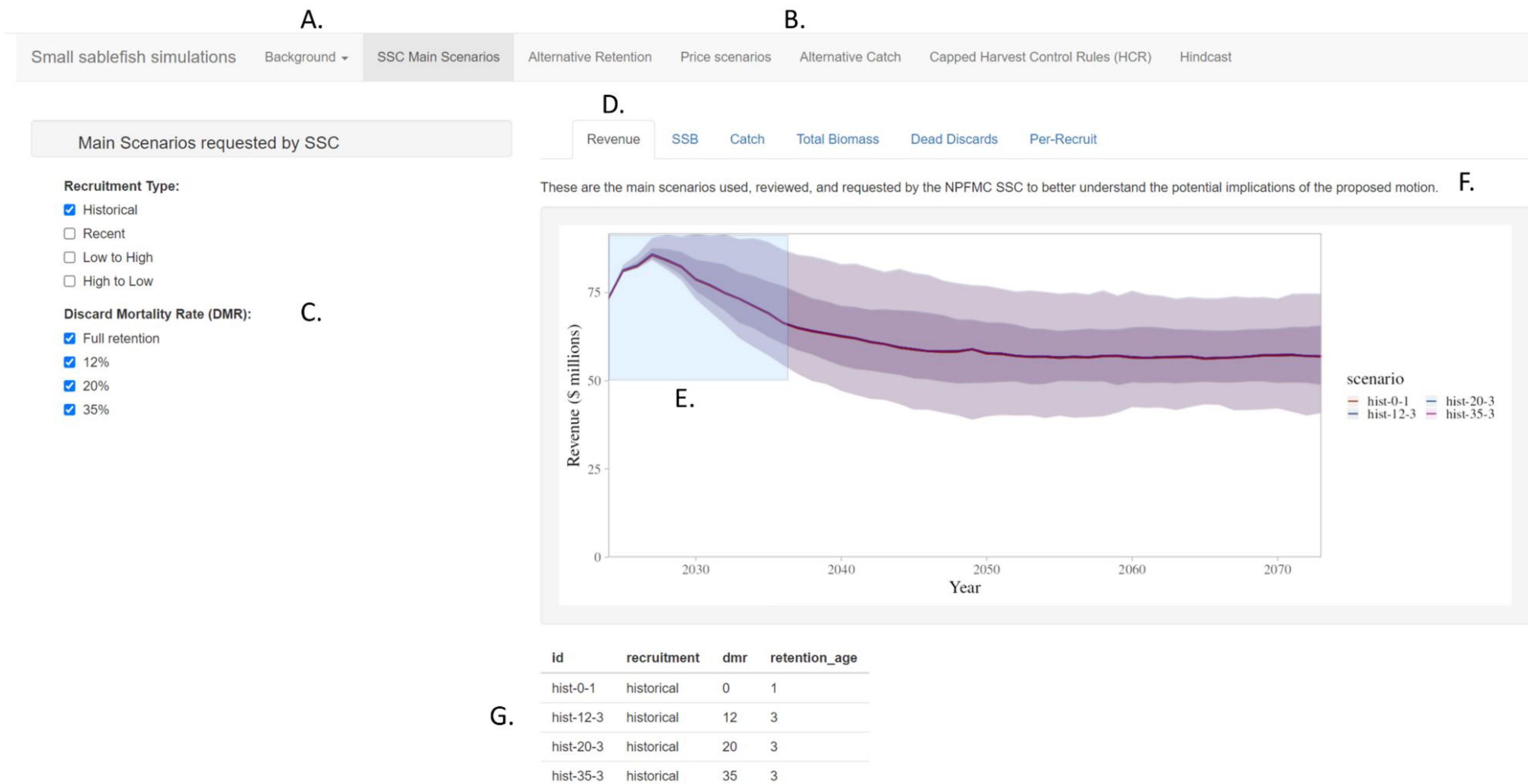

Figure 1. Screenshot illustrating the format and key features of the interactive decision-support tool, including (A) a ‘background’ tab (also the landing page) describing the purpose, assumptions, and how to use the tool; (B) scenario tabs for accessing each group of results; (C) interactive checkboxes to choose among the primary scenarios to be displayed; (D) performance metric tabs to choose the output metric to be displayed; (E) the interactive zoom box and pointer allowing users to zoom to a specific time period or performance metric value; (F) additional text explaining key assumptions or rationale for the given set of scenarios; and (G) a scenario table highlighting the key assumptions of each scenario currently on display.

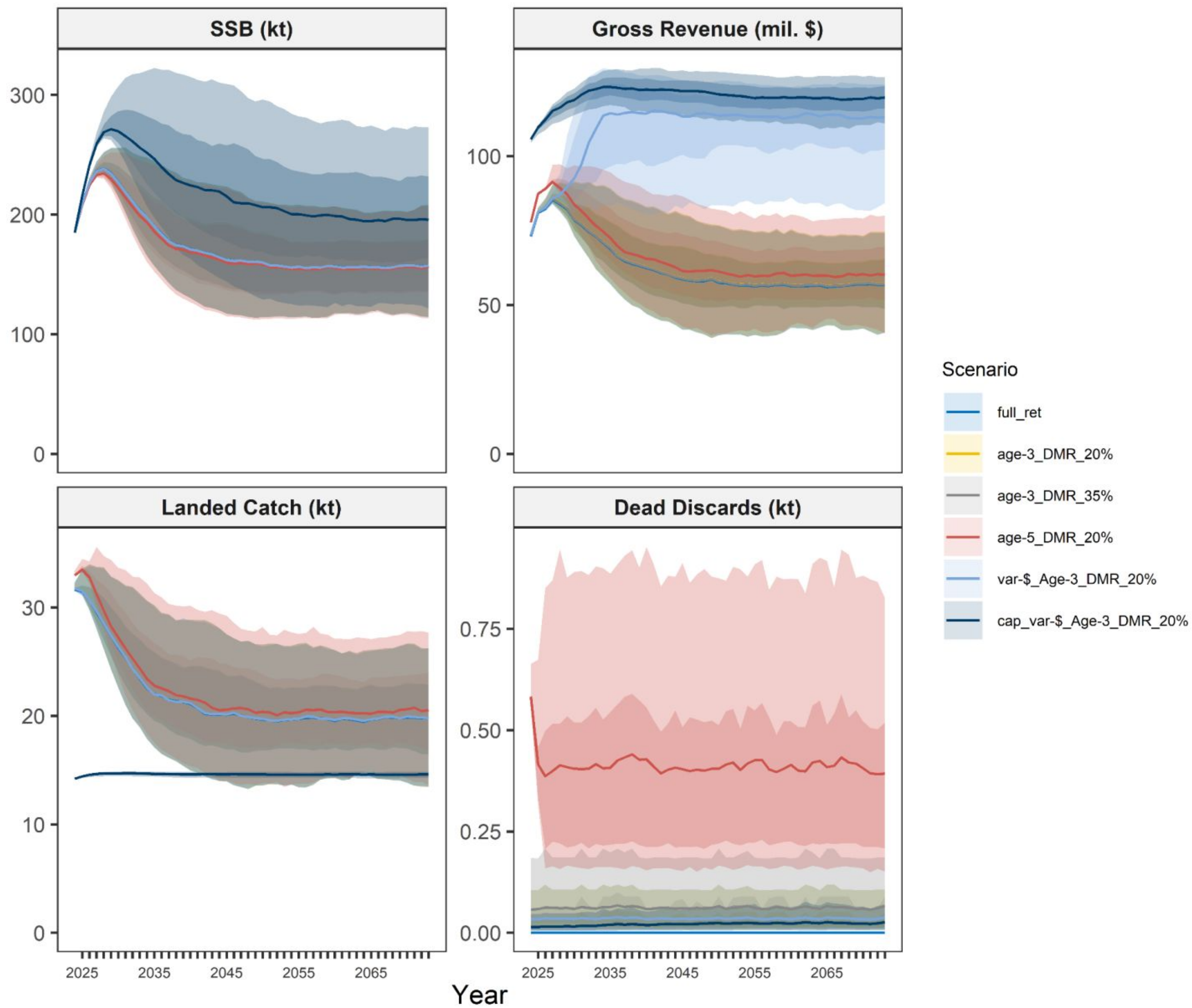

Figure 2. For each projection scenario, the resulting spawning stock biomass (SSB in kt; top left panel), gross revenue (millions of dollars, for fixed gear fleet only; top right panel), landed (retained) catch (kt; bottom left panel), and dead discards (kt; bottom right panel) by year. Lines represent the median (or mean for dead discards), while the 50% (darker) and 85% (lighter) simulation intervals across the 500 iterations are provided by the shading. See Table 1 for an explanation of scenario names.

Appendix A

Table A1. Model equations and primary fixed inputs for the sablefish case study.

Derived quantity	Equation	Description
Recruitment (*R*)	$R_{Sex,Year} = 0.5 * \left(x \in_R \overline{Recruit}\right)$	The set *Recruit* contains the 2023 SAFE recruitment estimates from 1979—2021 where recruitment occurs at age-2.
Weight-at-Age (*Wt*)	Input	See Table S1.
Weight Conversion	$Round\_Weight = \frac{Dressed\_Weight}{0.63}$	For converting size grade data in dressed weight to whole weight for use in the projections of gross revenue; conversion from NPFMC (2024b).
Maturity-at-Age (*Mat*)	Input	See Table S1.
Selectivity (*S*)	Input	See Table S1 and Figure S1.
Retention (*Ret*)	Input	Equal to 100% for the trawl fleet; for the fixed gear fleet it can be 100% for all ages (*full_ret* Scenario), 0% at age-2 and 100% at all other ages (i.e., knife-edge retention starting at age-3), or 0% at age-2,3, and 4 and 100% at all other ages (i.e., knife-edge retention starting at age-5; *age-5_DMR_20%*; see Figure S1).
Discard Mortality Rate (*DMR*)	Input	Equal to 0%, 20%, or 35%, depending on the scenario (See Table 1).
Price-at-Age (*P*)	Input	Price ($) per kg in round weight, which was converted from $ per lbs. dressed weight (see Tables S1-S2).
Natural Mortality (*M*)	$M_{Sex,Age} = 0.113$	From the 2023 SAFE.
Fishing Mortality (*F*) to Achieve Acceptable Biological Catch (ABC)	$F_{ABC} = \begin{cases} F_{40\%}, & if\ SSB_{Year} > SSB_{SPR40\%} \\ F_{40\%} * \frac{\frac{SSB_{Year}}{SSB_{SPR40\%}} - 0.05}{0.95}, & if\ SSB_{Year} \leq SSB_{SPR40\%} \\ 0, & if\ SSB_{Year} < 0.05 * SSB_{SPR40\%} \end{cases}$	The sloping NPFMC $F_{40\%}$ harvest control rule, where $F_{40\%} = 0.086$ under full retention, but differs slightly for each discarding scenario.
Yearly Fishing Mortality Multiplier	$F_{Mult,Year} = ABC_{Prop} * F_{ABC}$	The proportion of the ABC harvested (ABC_{Prop}) is 66%.
Landed Fishing Mortality-at-Age	$F^{Fleet}_{Landed,Sex,Age,\,Year} = F_{Mult,\,Year} * Prop_{Fleet} * S^{Fleet}_{Sex,Age} * Ret^{Fleet}_{Sex,Age}$	Fleets include the fixed gear fleet and the trawl gear fleet; the proportion of the fishing mortality coming from the fixed gear fleet ($Prop_{Fixed\ Gear}$) is 0.745.
Discarded Fishing Mortality-at-Age	$F^{Fleet}_{Disc,\,Sex,Age,\,Year} = F_{Mult,\,Year} * Prop_{Fleet} * S^{Fleet}_{Sex,Age} * \left(1 - Ret^{Fleet}_{Sex,Age}\right) * DMR$	Fishing mortality due to discarding.
Total Fishing Mortality by Fleet and Age	$F^{Fleet}_{Tot,\,Sex,Age,\,Year} = F^{Fleet}_{Landed,Sex,\,Age,\,Year} + F^{Fleet}_{Disc,\,Sex,Age,\,Year}$	Total fishing mortality by fleet.

Total Fishing Mortality-at-Age	$F_{Tot,Sex,Age,Year} = \sum_{Fleet} F^{Fleet}_{Tot,Sex,\ Age,\ Year}$	Total population fishing mortality summed across all fleets.
Total Mortality (*Z*)-at-Age	$Z_{Sex,Age,Year} = F_{Tot,Sex,Age,Year} + M_{Sex,Age}$	Total mortality-at-age.
Abundance-at-Age (*N*)	$N_{Sex,Age+1,\ Year+1} = N_{Sex,Age,Year} e^{-Z_{Sex,Age,Year}}$	Projected abundance, where abundance at age-2 (i.e., new recruitment) is equal to $R_{Sex,Year}$.
Spawning Stock Biomass (*SSB*)	$SSB_{Year} = \sum_{Age} (Mat_{Age} * N_{Fem,Age,Year} e^{-Spawn\_Fract * Z_{Fem,Age,Year}})$	Note that spawning occurs in January, so SSB is not reduced for mortality during the year.
Retained Catch-at-Age (*CAA*) by Fleet	$CAA^{Fleet}_{Sex,Age,Year} = N_{Sex,Age,Year} * (1 - e^{-Z_{Sex,Age,Year}}) \frac{F^{Fleet}_{Landed,\ Sex,\ Age,\ Year}}{Z_{Sex,Age,Year}}$	Retained (landed) catch-at-age by fleet in numbers.
Retained Yield (*Y*) by Fleet	$Y^{Fleet}_{Sex,Year} = \sum_{Age} Wt_{Sex,\ Age} * CAA^{Fleet}_{Sex,Age,Year}$	Retained landings in weight by fleet.
Dead Discards-at-Age (*DAA*) by Fleet	$DAA^{Fleet}_{Sex,Age,Year} = N_{Sex,Age,Year} * (1 - e^{-Z_{Sex,Age,Year}}) \frac{F^{Fleet}_{Disc,\ Sex,\ Age,\ Year}}{Z_{Sex,Age,Year}}$	Dead discards-at-age by fleet in numbers.
Dead Discards (*D*) by Fleet	$D^{Fleet}_{Sex,Year} = \sum_{Age} Wt_{Sex,\ Age} * DAA^{Fleet}_{Sex,Age,Year}$	Dead discards in weight by fleet.
Gross Revenue (*R*)	$R^{Fixed\_Gear}_{Sex,Year} = \sum_{Age} Wt_{Sex,\ Age} * CAA^{Fixed\_Gear}_{Sex,Age,Year} * Price_{Sex,Age,Year}$	Total gross revenue by sex and year for the fixed gear fleet *only*; price was converted from size grade to age (see Tables S1-S2) and was assumed time-invariant based on 2023 prices for most scenarios, except when dynamic prices were assumed.
Depletion	$\%SSB_{SPR100\%_{Year}} = \frac{SSB_{Year}}{SSB_{SPR100\%}}$	$SSB_{SPR100\%}$ = 300 kt and $SSB_{SPR40\%}$ = 0.4 * $SSB_{SPR100\%}$ = 120 kt.